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WATER TRACE ELEMENTS NUMBER 2

Raymond J. Lishka, et al

Environmental Control Administration
Cincinnati, Ohio

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WATER TRACE ELEMENTS NO. 2

STUDY NUMBER 26

Report of a Study Conducted by the

ANALYTICAL REFERENCE SERVICE

Raymond J. Lishka and Earl F. McFarren

TRAINING PROGRAM

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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J.M. Matthews, Chemist, Analytical Reference Service, assisted in preparing the sample and checked its accuracy and stability by performing many analyses of aliquots of the sample both before and after it was distributed.

Paul W. Britton, Computer Sciences, Office of the Director, programmed a computer to statistically analyze the data.

FOREWORD

The Analytical Reference Service (ARS) is conducted by the Environmental Health Sciences and Engineering Training Program of the Robert A. Taft Sanitary Engineering Center to evaluate laboratory methods in the environmental field. Cooperative studies by member organizations that analyze identical samples and critically review methodology provide the mechanism for:

> Evaluation of analytical procedures, including precision and accuracy, by comparison of the procedures and results reported by participating laboratories.
>
> Exchange of information regarding method characteristics.
>
> Improvement or replacement of existing methods by development of more accurate procedures, and development of new methodology for determination of new pollutional compounds.

Samples are designed to contain measured amounts of selected constituents. Decisions as to qualitative makeup are made by the ARS staff, the membership, and consultants. Notice of each study is sent to the entire membership.

To those who desire to participate, a portion of the study sample is sent, along with data forms for reporting numerical values, a critique of the procedures used, comments on modifications, sources of error, difficulties encountered, or other pertinent factors. The results and comments received are compiled, and a report of each study is prepared.

Initially directed toward examination of water, studies now include air, milk, and food. Some studies are periodically repeated for the advantage of new members, to evaluate new methods, or to reevaluate existing methods.

The selection of studies is guided by the responses to questionnaires periodically circulated among the membership, which now includes 295 Federal, state, and municipal agencies; industries; universities; consulting firms; and foreign agencies.

James P. Sheehy
Director, Training Program

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STUDIES COMPLETED AND REPORTED

Water-Minerals	Calcium, magnesium, hardness, sulfate, chloride, alkalinity, nitrite, nitrate, sodium, and potassium. Studies completed in 1956, 1958, and 1961.
Water-Metals	Lead, copper, cadmium, aluminum, chromium, iron, manganese, and zinc; studies completed in 1957 and 1962. These same metals plus silver; study completed in 1965.
Water-Fluoride	Fluoride in the presence and absence of interferences, with and without distillation by a specified procedure. Studies completed in 1958 and 1961.
Water-Radioactivity	Gross beta activity; studies completed in 1959 and 1961. Gross beta and strontium-90 activity; study completed in 1963.
Water-Surfactant	Surfactant in various waters. Studies completed in 1959 and 1963.
Water-Oxygen Demand	Biochemical oxygen demand and chemical oxygen demand; study completed in 1960. Chemical oxygen demand; study completed in 1965.
Water-Trace Elements	Arsenic, boron, selenium, and beryllium. Study completed in 1962. These same metals plus vanadium; study completed in 1966.
Freshwater Plankton	Evaluation of the precision and accuracy obtainable by the use of various methods of plankton counting and identification. Study completed in 1964.
Air-Inorganics	Chloride, sulfate, fluoride, and nitrate in aqueous solution and on glass-fiber hi-vol filter mats. Study completed in 1958.
Air-Lead	Filter paper tape impregnated with lead. Study completed in 1961.
Air-Particulates	Microscopic identification of some common atmospheric particulates. Study completed in 1964.

Air-Sulfur Dioxide	Sulfur dioxide in air by a specified method. Study completed in 1963.
Water-Pesticides	Lindane, heptachlor epoxide, DDE and dieldrin in water. Study completed in 1965.
Food-Pesticides	DDT in milk. Study completed in 1962. Lindane, heptachlor epoxide, DDE and dieldrin in food. Study completed in 1965.

PARTICIPANTS IN THIS STUDY

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Brown and Caldwell Laboratories, San Francisco, California
Brush Beryllium Company, Elmore, Ohio
California State Department of Public Health, Branch Public Health Laboratory, Los Angeles
California State Department of Public Health, Sanitation and Radiation Laboratory, Berkeley
California Water Service Company, San Jose
Colorado Department of Public Health, Division of Laboratories, Denver
Connecticut State Department of Health, Laboratory Division, Hartford
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Department of National Health and Welfare, Ottawa, Ontario, Canada
Department of Water and Power, Los Angeles, California
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New Hampshire Water Pollution Commission, Concord
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New York State Conservation Department, Scottsville
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North Carolina State Board of Health, Raleigh
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ABSTRACT

A sample containing selenium, beryllium, boron, arsenic, and vanadium was analyzed in triplicate by 59 laboratories. A total of 600 determinations was submitted. Participants were requested to use new methods from the 12th edition of Standard Methods for the Examination of Water and Wastewater for the measurement of selenium and arsenic. Also suggested were an aluminon method for beryllium, the curcumin method for boron in Standard Methods, and a gallic acid procedure for vanadium by Fishman and Skougstad. All five methods were found to give sufficient accuracy and precision for water analysis and were generally considered to be simple, rapid, and reproducible. Tabulated results, statistical evaluation, and comments on the methods are presented.

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WATER TRACE ELEMENTS NO. 2

PURPOSE OF THE STUDY

This second study of water trace elements is similar in design to the first study conducted in 1962. The study was repeated because of requests from many Analytical Reference Service members who wanted to compare individual laboratory results and evaluate current procedures. In addition, the new 12th edition of Standard Methods for the Examination of Water and Wastewater contains new analytical procedures, and this study provided an opportunity to evaluate the new methods for arsenic and selenium, as well as the methods currently employed for the measurement of beryllium, boron, and vanadium. Procedures for the latter three were suggested by the Analytical Reference Service for consideration by participants who had no favorite method for these determinations.

DESIGN OF THE STUDY

To ensure greater sample stability and reduce shipping costs, the water sample was prepared as a concentrated solution, and shipped in sealed glass ampoules. It consisted of sterile, distilled, deionized water containing the following compounds:

Compound	Element	mg/l
SeO_2	Selenium	4.0
$BeSO_4$ $4H_2O$	Beryllium	50.0
H_3BO_3	Boron	48.0
As_2O_3	Arsenic	8.0
NH_4VO_3	Vanadium	1.2

Participants were instructed to dilute 5 ml of sample to 1 liter with good quality distilled water. Analyses of the diluted sample, in triplicate, were requested for each element measured. Values were to be reported to the nearest thousandth milligram per liter, and the method used was to be referenced.

TREATMENT OF THE DATA

Upon receipt of the results of analyses from each participant, the data were reviewed. In case of a suspected mathematical error, the reporting laboratory was asked to check their calculations and, if necessary, submit a corrected value.

Before any comprehensive statistical treatment of the data was undertaken, the distribution of the data was determined by plotting the mean of each participant's results on probability paper. Values showing a gross deviation from the normal distribution were then rejected as nonrepresentative because of errors in calculation, dilution, or other indeterminate factors. These rejected values were excluded in all subsequent statistical calculations. The rejected values are circled on the probability plots in the appendix and are shown as broken bars on the bar graphs in the text.

Upon completion of the study, the data reported by each participant were transferred to punch cards and the statistical calculations done by electronic computer. To verify this initial programming of the computer, the statistical results were checked with a conventional desk calculator.

Some results of a few participants are not listed, since no entry can be made on a punch card or a desk calculator for values reported as less than (<) a given value.

DISCUSSION

SELENIUM

Thirty-eight members performed the selenium analyses. Their results are presented graphically in Figure 1. One result was rejected as an outlier; one result obtained by use of the starch iodide method was very low; one result of 0.019 mg/l was obtained by use of the Cheng procedure,[16] which is similar to the standard method except for the omission of the oxidation step. The other 35 results were obtained by the suggested standard method[1] and showed excellent accuracy and precision. In spite of numerous comments about the length of the procedure and the many transfers involved, apparently excellent results can be obtained. The procedure was designed to measure selenium in both the selenite and selenate form; the shorter Cheng procedure measures only selenite.

In Table 1, the agreement of the mean and median values with the true value, and the 50% range of $\pm$0.002 mg/l show excellent accuracy. The precision of the standard method is shown by the standard deviation of 0.0044 and 95% confidence limits of 0.021 $\pm$ 0.0014 mg/l. When all results are considered, these values remain essentially the same.

Since the amount of selenium present was only twice the threshold limit for drinking water, the standard method appears to be sufficiently accurate and precise for this measurement.

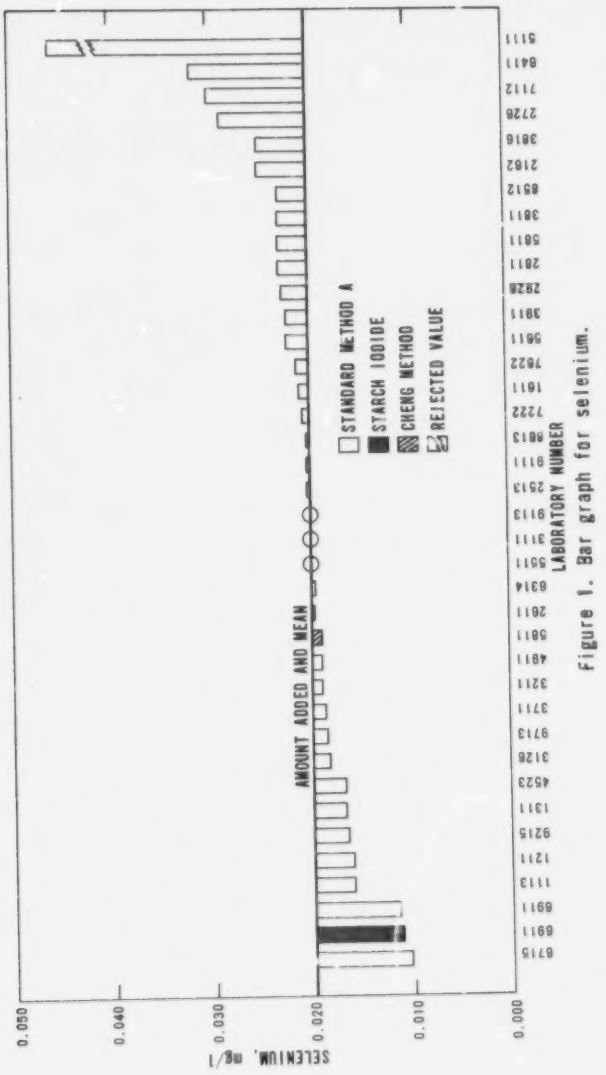

Figure 1. Bar graph for selenium.

Table 1. SUMMARY OF STATISTICAL DATA FOR SELENIUM

(Amount added = 0.020 mg/l)

	3,3'-diaminobenzidine[a] 12th ed. Std. Methods
Number of results	35
Median	0.020 mg/l
Mean	0.021 mg/l
Standard deviation	0.0044 mg/l
50% Range	±0.002 mg/l
95% Confidence limits	0.021 ± 0.0014 mg/l
Coefficient of variation	±21.2%

[a] Reference 1.

The individual results reported by participants are assembled in Table A-1 of the appendix.

BERYLLIUM

Forty participants performed the beryllium analyses. Their results are presented graphically in Figure 2. Six of the results were rejected as outliers; one of these was obtained by use of the spectrograph[9] and another by the fluorimetric procedure.[13] Two other participants used the fluorimetric procedure,[13, 14] which produced slightly low results. Thirty-two of the retained values were obtained by the aluminon procedure[7] provided with the sample.

Table 2. SUMMARY OF STATISTICAL DATA FOR BERYLLIUM

(Amount Added = 0.250 mg/l)

	Aluminon[a]
Number of results	32
Median	0.249 mg/l
Mean	0.247 mg/l
Standard deviation	0.0176 mg/l
50% Range	±0.010 mg/l
95% Confidence limits	0.247 ± 0.0067 mg/l
Coefficient of variation	7.13%

[a] Reference 7.

In Table 2, the close agreement of the mean and median values with the true value and the 50% range of ± 0.010 mg/l show very good accuracy.

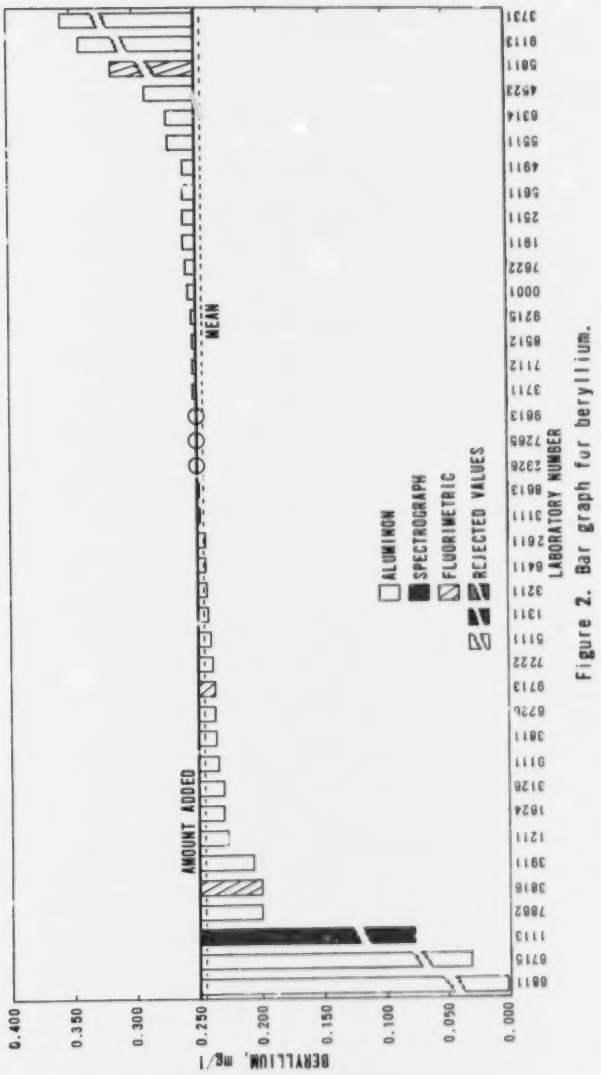

Figure 2. Bar graph for beryllium.

The standard deviation of ±0.0176 and the 95% confidence limits of 0.247 ± 0.0067 mg/l show good precision.

The aluminon-buffer solution's turbid appearance, which is normal, was disturbing to several participants, but caused no difficulty. Several participants objected to filtering the sample at the end of the procedure. The Analytical Reference Service staff has observed, however, that filtering a turbid water sample before addition of reagent results in a partial loss of beryllium. If filtration is required, the standards as well as the sample should be filtered just prior to reading the absorbance, to achieve satisfactory results.

The reported results for the measurement of beryllium are shown in Table A-2 of Appendix A.

BORON

Forty participants used six different methods to measure boron. Their results are presented graphically in Figure 3. One used a spectrograph[9] producing a slightly high result. One excellent result was obtained by use of the boron tetrafluoride extraction procedure.[12] Five results were obtained by the carmine procedure,[5] which showed poor precision; two of these results were rejected as outliers, two were very low, and one was slightly low. The potentiometric titration[19] used by two participants produced low results. One result obtained with quinalizarin[17] was slightly low. Results submitted by 30 participants using the curcumin method[2, 4] were generally good.

Table 3. SUMMARY OF STATISTICAL DATA FOR BORON

(Amount added = 0.240 mg/l)

	Curcumin[a]
Number of results	30
Median	0.244 mg/l
Mean	0.240 mg/l
Standard deviation	0.0547 mg/l
50% Range	±0.021 mg/l
95% Confidence limits	0.240 ± 0.0204 mg/l
Coefficient of variation	22.8%

[a] Reference 2.

In Table 3, the close agreement between the mean, median, and true values indicates good accuracy. The 50% range shows that at least half the results were within ±0.021 mg/l of the true value. The standard

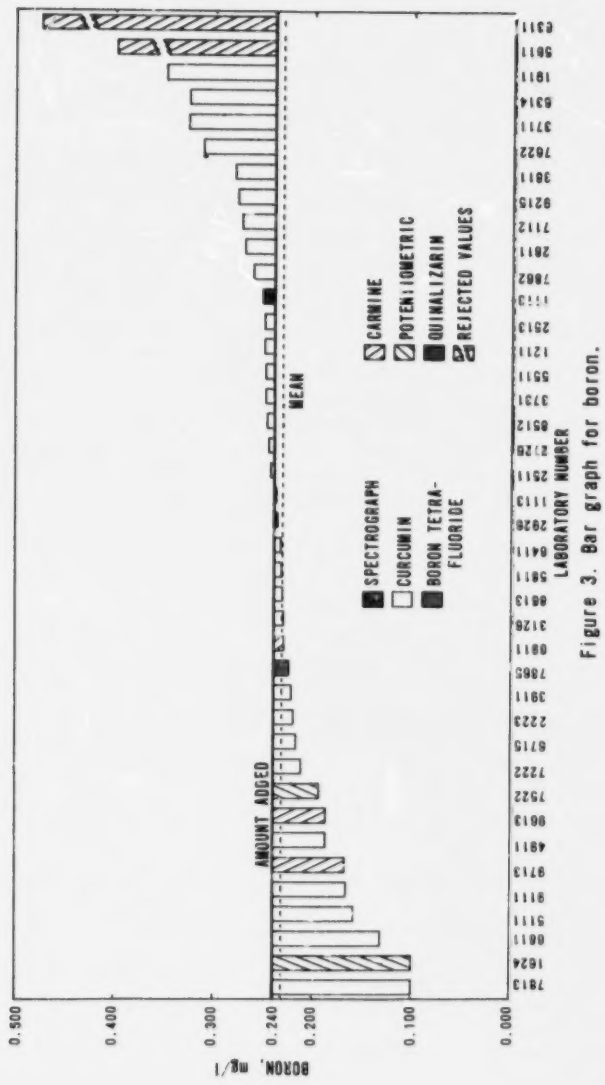

Figure 3. Bar graph for boron.

deviation and 95% confidence limits show that the precision is not as good as that of the other determinations in this study. The precision of the method might be improved if minor changes were made in the write-up of the procedure in Standard Methods. For example, several participants experienced creeping of the sample over the edge of the evaporating dish when the samples were evaporated in small dishes. This would be corrected if 100-ml evaporating dishes were used. Another possible source of error is the difference in volumes specified for the series of standards. Because a variation in the time to dryness will vary the color of the rosocyanine produced, the standards and samples should all be added in 1-ml amounts. Several participants had difficulty in judging when the samples had reached dryness. To ensure complete dryness, it was suggested that the procedure might be improved by requiring the samples to remain in the water bath for a specified time after apparent dryness is reached. An additional time in the water bath after complete dryness is reached has no observed adverse effect. The 11th edition of Standard Methods recommends leaving the evaporating dishes on the water bath for an additional 15 minutes after dryness is reached, whereas the 12th edition recommends removing the dishes from the water bath as soon as the contents appear dry and the odor of HCl is gone. The two procedures are identical otherwise.

The individual measurements for boron are given in Table A-3 of Appendix A.

ARSENIC

Of the 57 results submitted for arsenic measurement, 10 were rejected as outliers. The results are presented graphically in Figure 4. The rejected values included one determination by spectrograph,[9] one by the method of Vasak and Sedivec,[15] one by the standard Gutzeit procedure[6] and seven by the silver diethyldithiocarbamate procedure[3, 10] provided with the sample. The 47 retained results included one perfect result by a Gutzeit procedure;[18] the remainder were obtained by the procedure provided.

In Table 4, the agreement between the mean, median, and true values, and the 50% range of ± 0.004 mg/l show excellent accuracy. The standard deviation of 0.0055 and the 95% confidence limits of 0.040 ± 0.0016 mg/l show excellent precision. Since the concentration of arsenic in this sample was below the threshold limit for drinking water, the silver diethyldithiocarbamate method evidently is suitable for water analysis.

Some participants experienced difficulty with turbidity in the receiving solution, which undoubtedly was caused by carryover of excess water from the lead acetate scrubber. In addition to possible excess lead acetate solution in the scrubber, other critical points to check in the procedure are immediate closure of the apparatus after zinc is added; assurance that the

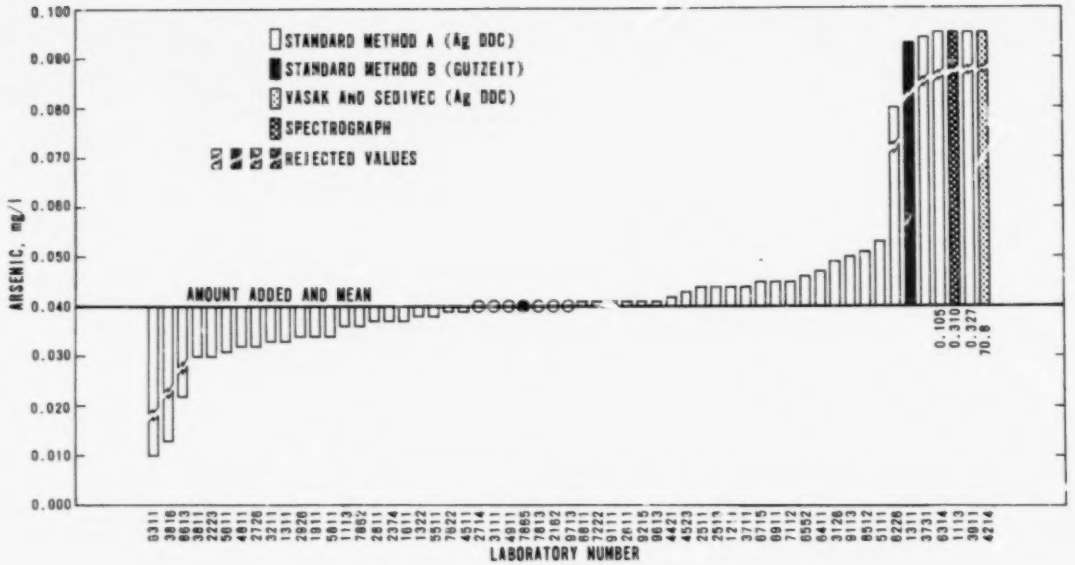

Figure 4. Bar graph for arsenic.

Table 4. SUMMARY OF STATISTICAL DATA FOR ARSENIC

(Amount added = 0.040 mg/l)

	Silver diethyl-dithiocarbamate[a]
Number of results	47
Median	0.040 mg/l
Mean	0.040 mg/l
Standard deviation	0.0055 mg/l
50% Range	±0.004 mg/l
95% Confidence limits	0.040 ± 0.0016 mg/l
Coefficient of variation	13.8%

[a] Reference 3.

system is gas tight; use of high quality zinc of uniform granular size; complete reduction of arsenic before generation of arsine; and prevention of back pressure in the generator, which may suck the reagent back into the scrubber. Conversely, too rapid evolution of arsine may blow reagent out of the absorber.

Although participants were requested to use the procedure from the 12th edition of Standard Methods, one participant reported using the method of Ballinger, Lishka and Gales which differs only in the wavelength specified for measuring the colored complex. This result was included with those obtained by the procedure provided.

The results reported by the participants for the measurement of arsenic are shown in Table A-4 of Appendix A.

VANADIUM

Twenty-four results obtained by the gallic acid procedure of Fishman and Skougstad[8] were submitted for vanadium measurement. These results are presented graphically in Figure 5. Two of these were rejected as outliers. One result of zero obtained with N-benzoyl-N-phenyl hydroxylamine[11] also was rejected.

The agreement between the mean, median and true values and the 50% range of 0.001 mg/l show that the gallic acid procedure produced excellent accuracy. Likewise, the standard deviation of ±0.0012 and 95% confidence limits of 0.006 ± 0.0005 mg/l show excellent precision. The method was found to be simple and reproducible. The most frequently mentioned difficulty was precipitation of the 2% gallic acid solution. The Analytical Reference Service staff followed the directions for preparation of reagents as given in the procedure and encountered no difficulty. It

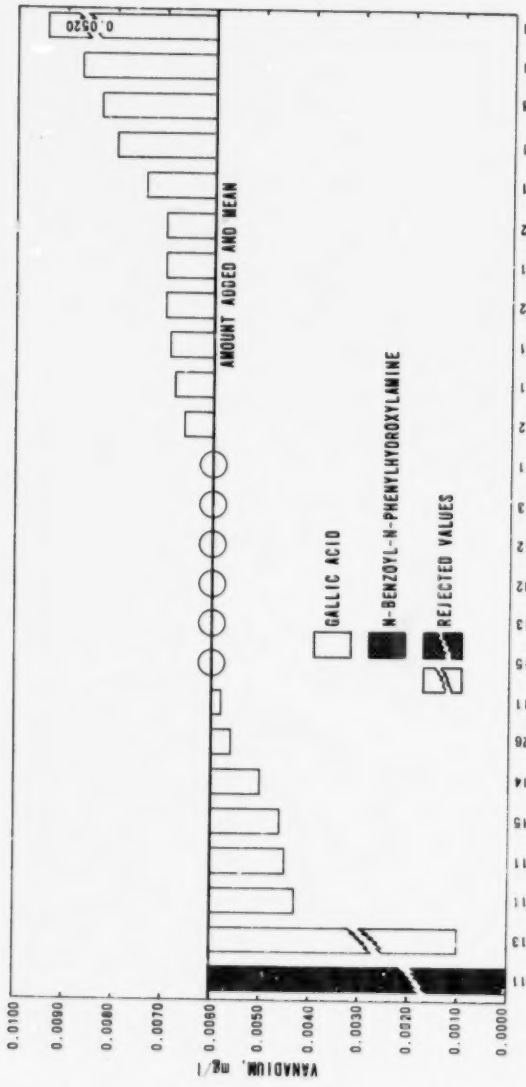

Figure 5. Bar graph for vanadium.

Table 5. SUMMARY OF STATISTICAL DATA FOR VANADIUM

(Amount added = 0.006 mg/l)

	Gallic acid[a]
Number of results	22
Median	0.006 mg/l
Mean	0.006 mg/l
Standard deviation	0.0012 mg/l
50% Range	±0.001 mg/l
95% Confidence limits	0.006 ± 0.0005 mg/l
Coefficient of variation	18.7%

[a] Reference 8.

was observed that the ammonium persulfate-phosphoric acid solution must be prepared at least 12 hours before use, although the procedure suggests approximately 24 hours. Reagents must be prepared each day and the procedure must be carefully followed, but the excellent results obtainable by this procedure indicate it is a suitable method for water analysis.

The reported results for the measurement of vanadium are shown in Table A-5 of Appendix A.

COMMENTS OF THE PARTICIPANTS

Selenium – A few participants reported that a good standard curve and good reproducibility were produced by the standard method. Several participants objected to the length of the procedure and believed the numerous transfers and evaporations were conducive to error. Excess permanganate in the oxidation step was reported to cause difficulties in the toluene extraction. One participant believed only 5 minutes for formation of piazselenol was inadequate. It was suggested that more complete recovery could be obtained by washing the flask twice with 5 ml of ammonia hydroxide in step 4.4;[1] in step 4.5, the beaker should be rinsed into the graduate to the 45-ml mark, the contents of the graduate poured into the separatory funnel, and then the graduate rinsed with 5 ml of distilled water that was then added to the funnel. One participant reported that after formation of piazselenol, the sample was adjusted to pH 8, made up to volume, and allowed to stand overnight. As a result, a precipitate formed, which caused an emulsion when the sample was shaken with toluene.

Beryllium – Several participants were disturbed by the turbid appearance of the aluminon-buffer solution and suggested that filtering should be done after the final dilution rather than before. More information

was desired as to whether any drying of the beryllium sulfate was necessary for preparation of a standard solution. One participant reported that the standard curve did not pass through zero, but that a higher series of standards produced a straight line passing through zero except for the 0.01-mg standard, which was off the curve. One participant who used the fluorimetric procedure with morin mentioned that positive errors are produced if distilled water or standards stored in polyethylene containers are used.

Boron – Several participants noted that the sample tended to creep out of the evaporating dish during the evaporation step, especially when 50-ml dishes were used. Comment was made that accuracy depends on the size and thickness of the evaporating dishes and also on the timing of evaporation. Difficulty was encountered in judging when the samples were evaporated to complete dryness. A fixed time for evaporation, such as 1 hour or 1 hour and 20 minutes, was suggested. Variation in the color of the blank was reported. According to the procedure, the standards consist of different volumes; this causes a variation in evaporation time, thereby introducing errors. Some believed reporting results to the nearest one thousandth of a milligram per liter was not justified.

Arsenic – The silver diethyldithiocarbamate method was judged to be simpler, more rapid, and more reproducible than either the Gutzeit or Heteropoly Blue methods. Some difficulty was encountered with stability of the reagent; the Fisher product appeared to be more stable than the Eastman product. One participant noted that to obtain reproducibility immediate closure of the arsine generator after zinc is added is required. Several participants used the arsine generator supplied by the Fisher Scientific Company with good results. Others devised modifications of the apparatus illustrated in the Standard Methods procedure. One design submitted by several participants involved the substitution of glass tubing drawn to a fine opening instead of the S-shaped receiver. A small test tube or cuvette was used as the receiver containing the reagent, and the capillary tube was inserted to the bottom to permit the arsine to evolve in fine bubbles through the reagent.

One participant used 5 ml of reagent instead of the 4 ml specified. Another participant used 6 ml of hydrochloric acid instead of the 5 ml specified, and claimed improved reproducibility.

Several participants believed that reporting results to the nearest one thousandth of a milligram per liter was not justified.

Several participants reported turbidity in the receiving solution, probably due to carryover from the lead acetate scrubber. This

was prevented in one case, by adding a glass-wool filter between the scrubber and receiver. Concern was expressed over the variety of wavelengths specified in different publications for the measurement of absorbance in this procedure. Some participants who felt that the concentration of arsenic in the sample was too low for accurate measurement either concentrated the sample by evaporation or used a larger aliquot and increased the volumes of reagents proportionately. One participant noted that analytical grade stannous chloride contains enough arsenic to produce erratic results. This effect was avoided by combining the potassium iodide, stannous chloride, and hydrochloric acid and adding a single carefully measured portion.

Vanadium – The gallic acid procedure was considered a simple method. Some difficulty was encountered with precipitation of the 2% gallic acid solution; this was overcome by one participant who used a double volume of 1% solution. It was stated that the reaction time is critical since the color intensifies on standing. Color will fail to develop if the ammonium persulfate is not adequately fresh and dry. One participant stated that mercury hydrolized out of solution and that the curve appeared to be non-linear from 0.06 to 0.08 µg. Another participant considered the method undesirable because of the unstable reagent, rigorous temperature control, and absorbance on the border of the ultra-violet region.

SUMMARY AND CONCLUSIONS

The method in the 12th edition of Standard Methods for measurement of selenium is accurate and precise, but somewhat lengthy. It is designed to measure selenium in both the selenite and selenate form. If it is known that the sample contains selenium in only the selenite form, the oxidation and reduction step can be omitted. The remainder of the procedure, which measures only selenite, is similar to the older Cheng procedure.

Thirty-five laboratories determined selenium by the standard method with a standard deviation of ±0.0044 and at least half of the results were within ± 0.002 mg/l of the known concentration of 0.020 mg/l.

All but four participants used the aluminon procedure, provided with the sample, for measurement of beryllium, and satisfactory precision and accuracy were obtained. The morin fluorimetric procedure used by three participants produced widely scattered results, which may be due to contact of the sample or reagents with polyethylene.

Thirty-two laboratories determined beryllium by the aluminon procedure with a standard deviation of ±0.0176 mg/l; at least half the results were within ±0.010 mg/l of the known concentration of 0.250 mg/l.

The curcumin procedure for boron measurement provided in Standard Methods was used by three-fourths of the participants. Good accuracy was obtained, but better precision would be desirable. Minor revisions of the procedure may improve the precision. The carmine procedure produced extremely scattered results. Good results were obtained by the boron tetrafluoride extraction method and by the spectrograph, used by one participant each. Potentiometric titration used by two participants produced low results.

Thirty laboratories determined boron by the curcumin procedure with a standard deviation of ± 0.0547 mg/l; at least half the results were within ± 0.021 mg/l of the known concentration of 0.240 mg/l.

For measurement of arsenic, the silver diethyldiethiocarbamate procedure in the 12th edition of Standard Methods was considered more rapid, simpler, and more reproducible than the Gutzeit or Heteropoly Blue methods. The accuracy and precision of the procedure were excellent; seven extremely divergent values were rejected, however. With careful adherence to the procedure, excellent results are obtainable, indicating that the method is suitable for water analysis.

Forty-six laboratories determined arsenic by the standard method using silver diethyldithiocarbamate with a standard deviation of ± 0.0055 mg/l; at least half the results were within ± 0.004 mg/l of the known concentration of 0.040 mg/l.

All participants in the vanadium measurement used the gallic acid procedure suggested by the Analytical Reference Service. Excellent precision and accuracy were obtained and the method was generally considered to be sensitive, simple and reproducible. Careful adherence to the procedure must be observed, however. The results indicate that the method is suitable for water analysis.

Twenty-two laboratories determined vanadium by the gallic acid procedure with a standard deviation of ± 0.0012 mg/l; at least half the results were within ± 0.001 mg/l of the known concentration of 0.006 mg/l.

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APPENDICES

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APPENDIX A.

TABULATION OF RESULTS

Table A-1. SELENIUM (0.020 mg/l)

Lab. No.	Results			Mean	Method	Reference
1113	0.016	0.016	0.016	0.0160	Diaminobenzidine	1
1211	0.012	0.016	0.020	0.0160	Diaminobenzidine	1
1311	0.014	0.018	0.018	0.0170	Diaminobenzidine	1
1611	0.020	0.020	0.023	0.0210	Diaminobenzidine	1
2162	0.022	0.025	0.028	0.0250	Diaminobenzidine	1
2513	0.019	0.020	0.022	0.0203	Diaminobenzidine	1
2611	0.019	0.019	0.021	0.0197	Diaminobenzidine	1
2726	0.0285	0.0290	0.0290	0.0288	Diaminobenzidine	1
2811	0.024	0.023	0.022	0.0230	Diaminobenzidine	1
2926	0.024	0.022	0.022	0.0227	Diaminobenzidine	1
3111	0.020	0.020	-----	0.0200	Diaminobenzidine	1
3126	0.018	0.016	0.021	0.0183	Diaminobenzidine	1

(Table A-1 continued)

Lab. No.	Results			Mean	Method	Reference
3211	0.020	0.017	0.020	0.0190	Diaminobenzidine	1
3711	0.018	0.019	0.019	0.0187	Diaminobenzidine	1
3811	0.025	0.021	-----	0.0230	Diaminobenzidine	1
3816	0.025	0.025	0.025	0.0250	Diaminobenzidine	1
3911	0.024	0.022	0.021	0.0223	Diaminobenzidine	1
4523	0.015	0.018	0.017	0.0167	Diaminobenzidine	1
4911	0.020	0.018	0.019	0.0190	Diaminobenzidine	1
5111	0.049	0.043	-----	0.0460	Diaminobenzidine	1
5511	0.020	0.020	0.020	0.0200	Diaminobenzidine	1
5611	0.022	0.025	0.020	0.0223	Diaminobenzidine	1
5811	0.024	0.023	0.022	0.0230	Diaminobenzidine	1
5811	0.019	-----	-----	0.0190	Diaminobenzidine	16
6314	0.019	0.020	0.020	0.0197	Diaminobenzidine	1
6411	0.030	0.030	0.035	0.0317	Diaminobenzidine	1

(Table A-1 continued)

Lab. No.	Results			Mean	Method	Reference
6715	0.0097	0.0103	0.0113	0.0104	Diaminobenzidine	1
6911	0.0112	------	------	0.0112	Starch Iodide	–
6911	0.0115	------	------	0.0115	Diaminobenzidine	1
7112	0.030	0.030	0.030	0.0300	Diaminobenzidine	1
7222	0.021	0.020	0.021	0.0207	Diaminobenzidine	1
7622	0.025	0.019	0.020	0.0213	Diaminobenzidine	1
8512	0.024	0.023	0.022	0.0230	Diaminobenzidine	1
8613	0.020	0.020	0.021	0.0203	Diaminobenzidine	1
9111	0.020	0.021	0.020	0.0203	Diaminobenzidine	1
9113	0.02	0.02	0.02	0.0200	Diaminobenzidine	1
9215	0.0150	0.0180	-----	0.0165	Diaminobenzidine	1
9713	0.019	0.018	-----	0.0185	Diaminobenzidine	1

Table A-2. BERYLLIUM (0.250 mg/l)

Lab. No.	Results			Mean	Method	Reference
0001	0.256	0.256	0.256	0.256	Aluminon	7
1113	0.080	0.080	0.073	0.078	Spectrograph	9
1211	0.220	0.230	0.230	0.227	Aluminon	7
1311	0.240	0.240	0.246	0.242	Aluminon	7
1624	0.230	0.230	0.230	0.230	Aluminon	7
1911	0.26	0.24	0.28	0.260	Aluminon	7
2511	0.256	0.260	0.264	0.260	Aluminon	7
2611	0.236	0.245	0.252	0.244	Aluminon	7
2926	0.250	0.249	0.250	0.250	Aluminon	7
3111	0.246	0.248	0.250	0.248	Aluminon	7
3126	0.23	0.23	0.23	0.230	Aluminon	7
3211	0.250	0.244	0.235	0.243	Aluminon	7
3711	0.250	0.255	0.255	0.253	Aluminon	7
3731	0.3480	0.3760	0.3460	0.357	Aluminon	7

(Table A-2 continued)

Lab. No.	Results			Mean	Method	Reference
3811	0.238	0.242	0.228	0.236	Aluminon	7
3816	0.200	0.200	0.200	0.200	Fluorimetric	13
3911	0.22	0.20	0.20	0.207	Aluminon	7
4523	0.288	0.288	0.293	0.290	Aluminon	7
4911	0.26	0.26	0.26	0.260	Aluminon	7
5111	0.239	0.239	0.241	0.240	Aluminon	7
5511	0.268	0.272	0.276	0.272	Aluminon	7
5611	0.280	0.240	0.260	0.260	Aluminon	7
5811	0.317	0.317	0.317	0.317	Fluorimetric	13
6226	0.24	0.24	0.23	0.237	Aluminon	7
6314	0.28	0.28	0.26	0.273	Aluminon	7
6411	0.234	0.244	0.254	0.244	Aluminon	7
6715	0.0318	0.0320	0.0320	0.032	Aluminon	7
6811	0.002	0.002	0.002	0.002	Aluminon	7

(Table A-2 continued)

Lab. No.	Results			Mean	Method	Reference
7112	0.24	0.27	0.25	0.253	Aluminon	7
7222	0.234	0.244	0.240	0.239	Aluminon	7
7265	0.258	0.243	-----	0.250	Aluminon	7
7622	0.260	0.260	0.254	0.258	Aluminon	7
7862	0.200	0.200	0.200	0.200	Aluminon	7
8512	0.240	0.280	0.240	0.253	Aluminon	7
8613	0.246	0.248	0.252	0.249	Aluminon	7
9111	0.230	0.232	0.240	0.234	Aluminon	7
9113	0.37	0.34	0.32	0.343	Aluminon	7
9215	0.268	0.248	0.247	0.254	Aluminon	7
9613	0.252	0.250	0.254	0.252	Aluminon	7
9713	0.23	0.24	0.24	0.237	Fluorimetric	14

Table A-3. BORON (0.240 mg/l)

Lab. No.	Results			Mean	Method	Reference
1113	0.258	0.250	0.244	0.251	Spectrograph	9
1113	0.236	0.243	0.236	0.238	Curcumin	4
1211	0.255	0.245	0.250	0.250	Curcumin	4
1624	0.1	0.1	0.1	0.100	Potentiometric	19
1911	0.37	0.32	0.36	0.350	Curcumin	4
2223	0.22	0.22	-----	0.220	Curcumin	4
2511	0.250	0.251	0.228	0.243	Curcumin	4
2513	0.265	0.250	0.235	0.250	Curcumin	4
2726	0.240	0.240	0.255	0.245	Curcumin	4
2811	0.272	0.272	0.267	0.270	Curcumin	4
2926	0.24	0.24	0.23	0.237	BF_4-extraction	12
3126	0.23	0.26	0.20	0.230	Curcumin	2
3711	0.325	0.325	0.330	0.327	Curcumin	4
3731	0.2675	0.260	0.220	0.249	Curcumin	4

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(Table A-3 continued)

Lab. No.	Results			Mean	Method	Reference
3811	0.290	0.270	-----	0.280	Curcumin	4
3911	0.225	0.210	0.230	0.222	Curcumin	4
4911	0.2	0.18	0.18	0.187	Curcumin	4
5111	0.158	0.160	0.160	0.159	Curcumin	4
5511	0.250	0.250	0.248	0.249	Curcumin	4
5611	0.2	0.4	0.6	0.400	Carmine	5
5811	0.234	0.234	0.229	0.232	Curcumin	4
6311	4.79	4.70	4.61	4.70	Carmine	5
6314	0.33	0.32	0.33	0.327	Curcumin	4
6411	0.230	0.234	0.235	0.233	Curcumin	4
6715	0.21	0.23	0.21	0.217	Curcumin	4
6811	0.132	0.132	0.130	0.131	Curcumin	2
6911	0.23	0.23	-----	0.230	Carmine	5
7112	0.27	0.27	0.28	0.273	Curcumin	4

(Table A-3 continued)

Lab. No.	Results			Mean	Method	Reference
7222	0.250	0.215	0.170	0.212	Curcumin	4
7522	0.186	0.190	0.206	0.194	Potentiometric	19
7622	0.320	0.336	0.280	0.312	Curcumin	4
7813	0.110	0.090	0.100	0.100	Curcumin	4
7862	0.259	0.261	0.262	0.261	Curcumin	4
7865	0.21	0.24	-----	0.225	Quinalizarin	17
8512	0.250	0.240	0.250	0.247	Curcumin	4
8613	0.224	0.250	0.220	0.231	Curcumin	4
9111	0.152	0.161	0.185	0.166	Curcumin	4
9215	0.29	0.34	0.20	0.277	Curcumin	4
9613	0.189	0.184	0.187	0.187	Carmine	5
9713	0.16	0.18	0.16	0.167	Carmine	5

Table A-4. ARSENIC (0.040 mg/l)

Lab. No.	Results			Mean	Method	Reference
1113	0.305	0.305	0.320	0.310	Spectrograph	9
1113	0.036	0.036	0.036	0.036	Silver DDC	3
1211	0.043	0.047	0.043	0.044	Silver DDC	3
1311	0.028	0.028	0.044	0.033	Silver DDC	10
1311	0.090	0.090	0.100	0.093	Gutzeit	6
1322	0.037	0.038	0.038	0.038	Silver DDC	3
1611	0.038	0.037	0.037	0.037	Silver DDC	3
1911	0.034	0.034	0.034	0.034	Silver DDC	3
2162	0.041	0.039	0.040	0.040	Silver DDC	3
2223	0.032	0.029	0.030	0.030	Silver DDC	3
2374	0.034	0.037	0.040	0.037	Silver DDC	3
2511	0.046	0.043	0.043	0.044	Silver DDC	3
2513	0.040	0.043	0.049	0.044	Silver DDC	3
2611	0.041	0.042	0.041	0.041	Silver DDC	3

(Table A-4 continued)

Lab. No.	Results			Mean	Method	Reference
2714	0.039	0.040	0.040	0.040	Silver DDC	3
2726	0.0315	0.0330	0.0323	0.032	Silver DDC	3
2811	0.0365	0.0365	0.0372	0.037	Silver DDC	3
2926	0.034	0.034	0.033	0.034	Silver DDC	3
3111	0.040	0.040	0.039	0.040	Silver DDC	3
3126	0.051	0.049	0.046	0.049	Silver DDC	3
3211	0.030	0.033	0.035	0.033	Silver DDC	3
3711	0.046	0.044	0.043	0.044	Silver DDC	3
3731	0.085	0.103	0.095	0.094	Silver DDC	3
3811	0.030	0.029	0.031	0.030	Silver DDC	3
3816	0.014	0.011	0.014	0.013	Silver DDC	3
3911	0.32	0.34	0.32	0.327	Silver DDC	3
4214	68.5	69.5	74.4	70.8	Silver DDC	15
4421	0.036	0.036	0.053	0.042	Silver DDC	3

(Table A-4 continued)

Lab. No.	Results			Mean	Method	Reference
4511	0.038	0.044	0.036	0.039	Silver DDC	3
4523	0.044	0.044	0.041	0.043	Silver DDC	3
4811	0.0314 0.0323	0.0329	0.0323	0.032	Silver DDC	3
4911	0.0414	0.0371	0.0414	0.040	Silver DDC	3
5111	0.056	0.052	0.052	0.053	Silver DDC	3
5511	0.039	0.038	0.038	0.038	Silver DDC	3
5611	0.033	0.029	-----	0.031	Silver DDC	3
5811	0.034	0.034	0.034	0.034	Silver DDC	3
6226	0.08	0.08	0.08	0.080	Silver DDC	3
6311	0.010	0.010	0.009	0.010	Silver DDC	3
6314	0.106	0.106	0.104	0.105	Silver DDC	3
6411	0.046	0.049	0.046	0.047	Silver DDC	3
6552	0.046	0.046	0.045	0.046	Silver DDC	3
6715	0.044	0.044	0.046	0.045	Silver DDC	3

(Table A-4 continued)

Lab. No.	Results			Mean	Method	Reference
6811	0.041	0.040	0.041	0.041	Silver DDC	3
6911	0.043	0.048	0.043	0.045	Silver DDC	3
7112	0.043	0.046	0.046	0.045	Silver DDC	3
7222	0.042	0.041	0.040	0.041	Silver DDC	3
7622	0.039	0.039	0.040	0.039	Silver DDC	3
7813	0.040	0.040	0.040	0.040	Silver DDC	3
7862	0.036	0.036	-----	0.036	Silver DDC	3
7865	0.045	0.035	-----	0.040	Gutzeit	15
8512	0.048	0.050	0.054	0.051	Silver DDC	3
8613	0.029	0.017	0.020	0.022	Silver DDC	3
9111	0.041	0.040	0.042	0.041	Silver DDC	3
9113	0.05	0.05	0.05	0.050	Silver DDC	3
9215	0.040	0.040	0.044	0.041	Silver DDC	3
9613	0.0426	0.0434	0.0383	0.041	Silver DDC	3
9713	0.039	0.041	0.040	0.040	Silver DDC	3

Table A-5. VANADIUM (0.006 mg/l)

Lab. No.	Results			Mean	Method	Reference
1311	0.000	0.000	0.000	0.0000	N-Benzoyl-N-phenyl hydroxylamine	11
2511	0.0069	0.0067	0.0068	0.0068	Gallic acid	8
2513	0.001	0.001	0.001	0.0010	Gallic acid	8
2926	0.009	0.009	0.007	0.0083	Gallic acid	8
3126	0.0053	0.0056	0.0059	0.0056	Gallic acid	8
3731	0.006	0.008	0.010	0.0080	Gallic acid	8
3811	0.052	0.052	0.052	0.0520	Gallic acid	8
3911	0.009	0.008	0.009	0.0087	Gallic acid	8
4911	0.0047	0.0040	0.0047	0.0045	Gallic acid	8
5511	0.007	0.007	0.007	0.0070	Gallic acid	8
5611	0.0075	0.0070	0.0078	0.0074	Gallic acid	8
6314	0.005	0.005	0.005	0.0050	Gallic acid	8
6411	0.006	0.006	0.006	0.0060	Gallic acid	8

(Table A-5 continued)

Lab. No.	Results			Mean		Reference
6715	0.0058	0.0061	0.0060	0.0060	Gallic acid	8
6811	0.004	0.005	0.004	0.0043	Gallic acid	8
7112	0.0066	0.0064	0.0068	0.0066	Gallic acid	8
7222	0.007	------	------	0.0070	Gallic acid	8
7622	0.007	0.007	0.007	0.0070	Gallic acid	8
7813	0.006	0.006	0.006	0.0060	Gallic acid	8
7862	0.006	0.006	0.006	0.0060	Gallic acid	8
8512	0.006	0.006	0.006	0.0060	Gallic acid	8
8613	0.006	0.006	0.006	0.0060	Gallic acid	8
9111	0.006 0.006	0.005	0.006	0.0058	Gallic acid	8
9215	0.0048	0.0043	-----	0.0046	Gallic acid	8

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APPENDIX B - PROBABILITY CURVES

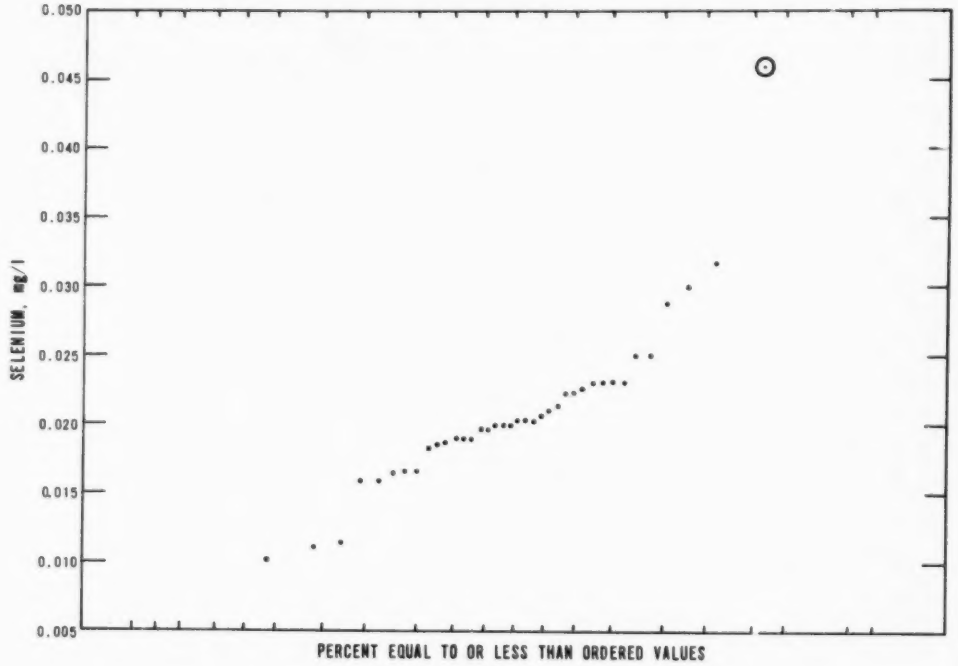

Figure B-1. Probability curve for selenium.

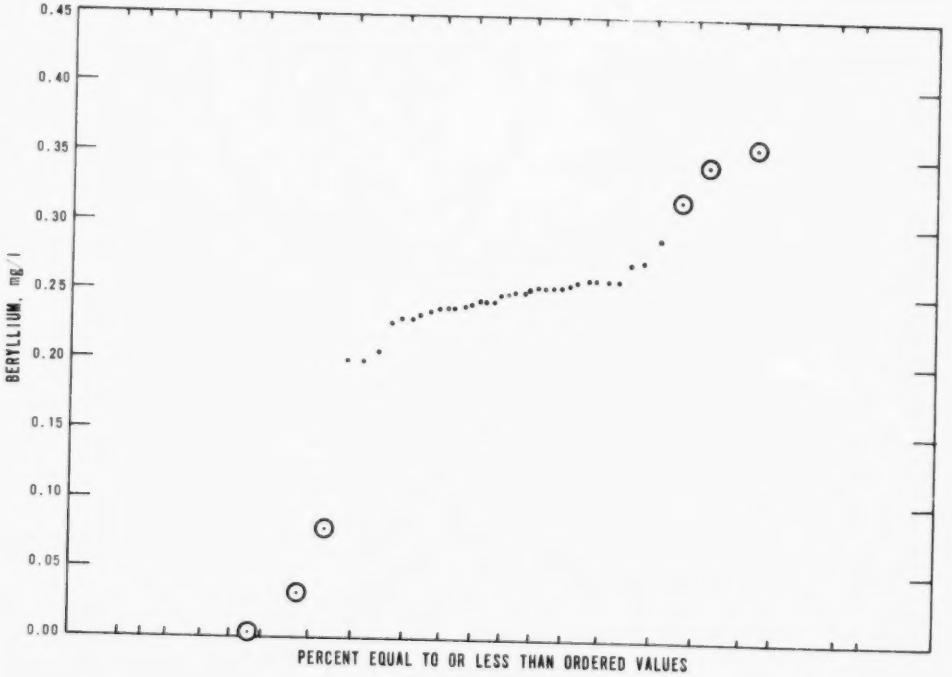

Figure B-2. Probability curve for beryllium.

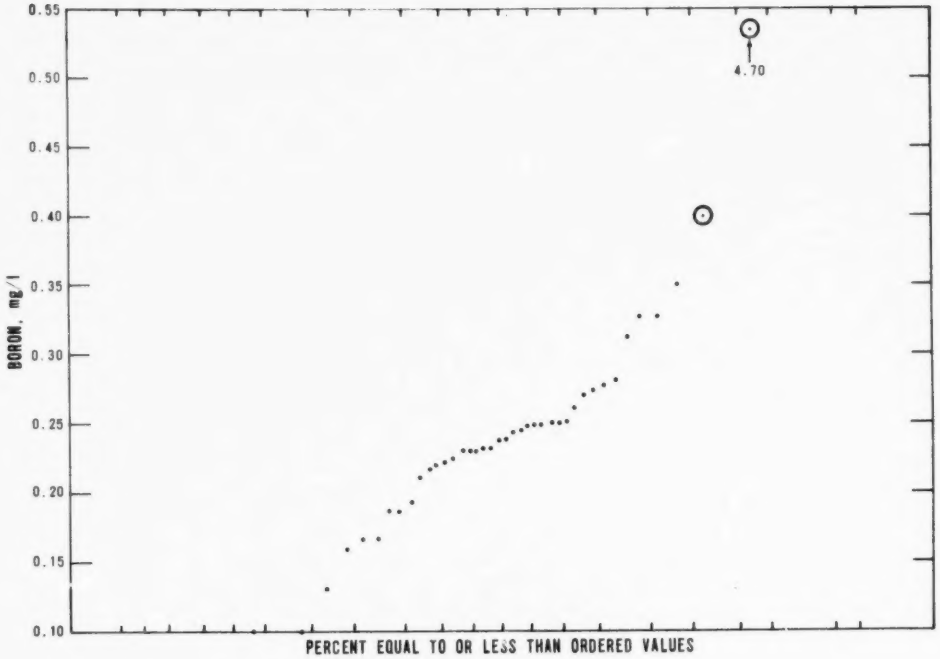

Figure B-3. Probability curve for boron.

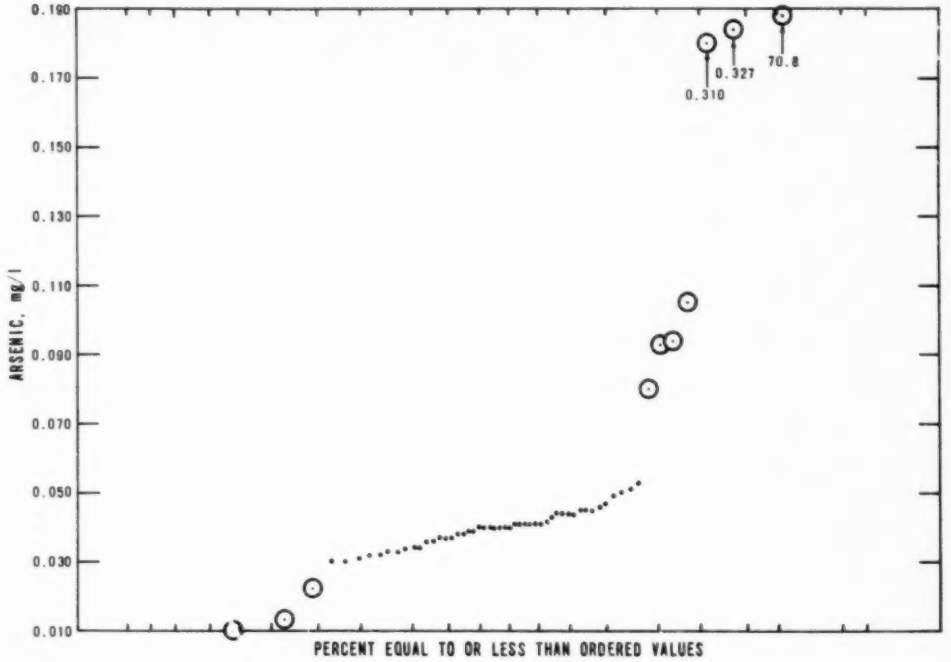

Figure B-4. Probability curve for arsenic.

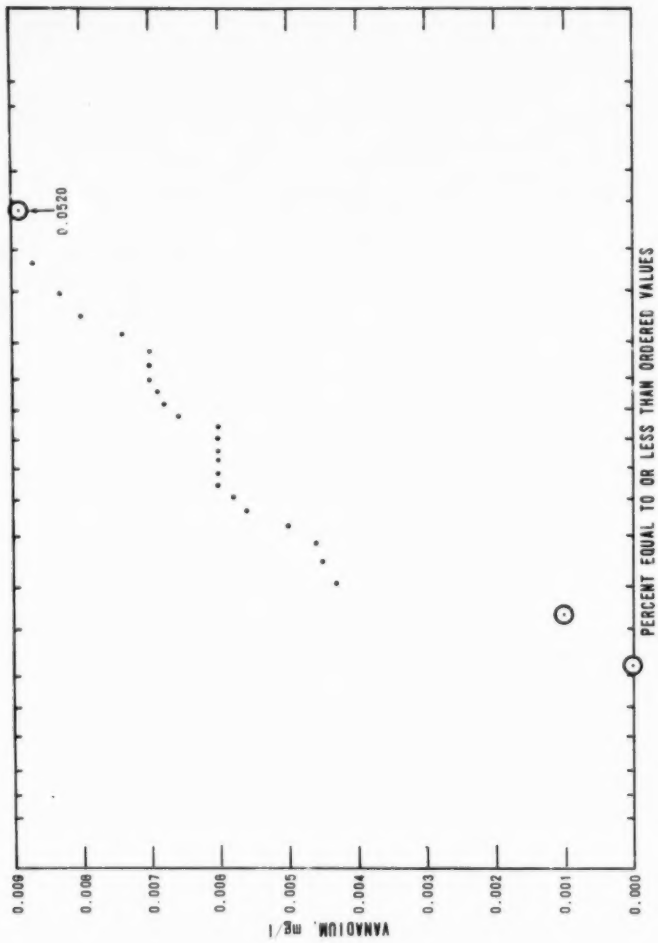

Figure B-5. Probability curve for vanadium.

APPENDIX C.

GLOSSARY OF STATISTICAL TERMS

A glossary of statistical terms defined as they are used in this report is presented to ensure uniform and complete understanding.

Arithmetic mean	The sum of a series of test results divided by the number of tests in the series.
Median	Halfway point in the readings when they have been arranged in order of size (the middle reading of an odd number of readings, or the average of the middle two for an even number).
Accuracy	The correctness of a measurement, or the degree of correspondence between the results and the true value (actual amount added).
Accuracy data	Measurements that relate to the difference between the average test results and the true value when the latter is known or assumed. The following measures apply:

50% Range – Shortest interval falling around the true value within which 50% of the data lies. For odd size samples, it is 50% rounded up.

Average deviation from true value – Average difference (when always considered as positive) between the mean determination for each laboratory and the true value.

Average percent deviation from true value – Average of the differences between a laboratory's replicate results and the true value expressed as percentages of the true value.

Mean error – The average difference with regard to sign of the test results from the true results. Also equal to the difference between the average of a series of test results and the true results.

Relative error – The mean error of a series of test results as a percentage of the true result.

Precision	A measure of the reproducibility of measurements, or the degree to which the measurements correspond to one another.
Precision data	Measurements that relate to the variation among the test results themselves, i.e., the scatter or dispersion of a series of test results without assumption of any prior information. The following measures apply:

Variance – Sum of squares of deviations of the average test results from the mean of the series divided by one less than the total number of average test results.

Standard deviation – Square root of the variance.

Coefficient of variation – Standard deviation expressed as a percentage of the mean of a series of laboratory results.

Range – Difference in magnitude between the highest and lowest laboratory mean.

Average percent deviation within laboratory – Average of the differences between the replicate results from a laboratory and the mean of their results, expressed as percentage of their mean.

Confidence limits – Limits within which the true mean of the population (the theoretically infinite number of possible replications of the analysis) will lie with a given probability.

APPENDIX D.

ANALYTICAL REFERENCE SERVICE MEMBERSHIP

Alabama State Department of Public Health, Montgomery
Alabama Water Improvement Commission, Montgomery
Arizona State Department of Public Health, Phoenix
Arkansas State Department of Health, Little Rock
California Department of Water Resources, Los Angeles
California Department of Water Resources, Sacramento
California State Department of Public Health, Los Angeles
California State Department of Public Health, Air and Industrial Hygiene Laboratory, Berkeley
California State Department of Public Health, Sanitation and Radiation Laboratory, Berkeley
Colorado Department of Public Health, Denver
Connecticut State Department of Health, Hartford
Delaware Water Pollution Commission, Dover
Florida State Board of Health, Jacksonville
Florida State Board of Health, Miami
Florida State Board of Health, Pensacola
Florida State Board of Health, Winter Haven
Georgia Department of Public Health, Atlanta
Hawaii Department of Health, Laboratories Branch, Honolulu
Hawaii Department of Health, Occupational and Radiological Health Section, Honolulu
Idaho Department of Health, Boise
Illinois Department of Air Pollution Control, Chicago
Illinois Department of Public Health, Springfield
Illinois Department of Public Health, State Sanitary Water Board, Springfield
Illinois State Water Survey Division, Champaign
Indiana State Board of Health, Indianapolis
Iowa State Hygienic Laboratory, Iowa City
Kansas State Department of Health, Topeka
Kentucky State Department of Health, Division of Laboratory Services, Frankfort
Kentucky State Department of Health, Public Health Laboratories Division, Frankfort
Kentucky State Department of Health, Radiological Health Program, Frankfort
Louisiana State Board of Health, New Orleans
Maryland State Department of Health, Baltimore
Massachusetts Department of Public Health, Amherst
Massachusetts Department of Public Health, Boston
Michigan State Department of Health, Lansing
Michigan Water Resources Commission, Lansing
Minnesota Department of Health, Engineering Laboratories Section, Minneapolis

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Missouri Department of Public Health and Welfare, Jefferson City
Montana Bureau of Mines and Geology, Butte
Montana State Board of Health, Helena
Nebraska Department of Agriculture and Economic Development, Lincoln
Nebraska State Department of Health, Lincoln
Nevada State Department of Health, Las Vegas
Nevada State Department of Health, Reno
New Hampshire Department of Health, Concord
New Hampshire Water Pollution Commission, Concord
New Jersey State Department of Health, Trenton
New Jersey State Department of Health, Environmental Health Laboratories, Trenton
New Mexico Department of Public Health, Sante Fe
New York State Air Pollution Control Board, Albany
New York State Conservation Department, Oakdale, L.I.
New York State Conservation Department, Scottsville
New York State Department of Air Pollution Control, New York City
New York State Department of Health, Albany
North Carolina Department of Water Resources, Raleigh
North Dakota State Department of Health, Bismarck
Ohio Department of Agriculture, Reynoldsburg
Ohio State Department of Health, Columbus
Oklahoma State Health Department, Oklahoma City
Oregon State Board of Health, Division of Sanitation and Engineering, Portland
Pennsylvania Department of Agriculture, Harrisburg
Pennsylvania Department of Health, Bureau of Air Pollution Control, Pittsburgh
Pennsylvania Department of Health, Division of Air Pollution Control, Harrisburg
Pennsylvania Department of Health, Division of Sanitary Engineering, Harrisburg
Puerto Rico Aqueduct and Sewer Authority
Puerto Rico Institute of Health Laboratories, Hato Rey
Rhode Island State Department of Health, Providence
South Carolina Department of Agriculture, Columbia
South Carolina Pollution Control Authority, Columbia
South Dakota Department of Health, Pierre
Tennessee Department of Public Health, Division of Industrial Hygiene Service, Nashville
Tennessee Department of Public Health, Radiological Health Service, Nashville
Tennessee Stream Pollution Control Board, Nashville
Texas State Department of Health, Austin
Utah State Department of Health, Salt Lake City
Vermont Department of Water Resources, Montpelier
Vermont State Department of Health, Barre
Vermont State Public Health Laboratory, Burlington

Virginia State Department of Health, Bureau of Industrial Hygiene, Richmond
Virginia State Department of Health, Bureau of Laboratories, Richmond
Virginia State Water Control Board, Richmond
Washington State Department of Health, Seattle
Washington State Food and Drug Laboratory, Seattle
West Virginia Department of Natural Resources, Charleston
Wisconsin Department of Agriculture, Madison
Wisconsin State Laboratory of Hygiene, Madison

MUNICIPAL AGENCIES

Baltimore Health Department, Maryland
Beaumont Health Department, Texas
Bureau of Air Pollution Control and Heating Inspection, Cincinnati, Ohio
Central District Filtration Plant, Chicago, Illinois
Charlotte Water Department, North Carolina
City of Allentown, Bureau of Water, Pennsylvania
City of Amarillo, Texas
City of Durham, Department of Water Resources, North Carolina
City of Erie, Bureau of Water, Pennsylvania
City of Los Angeles, Department of Water and Power, California
City of Miami, Alexander Orr, Jr. Water Treatment Plant, Florida
City of New York, Department of Health, New York
City of New York, Department of Health, Food and Drug Laboratory, New York
City of Niagara Falls, Division of Water Laboratories, New York
City Water Department of Chattanooga, Tennessee
City of Yonkers, Bureau of Water, New York
Department of Health and Hospitals, St. Louis, Missouri
Department of Public Works and Utilities, Flint, Michigan
Department of Service and Buildings, Dayton, Ohio
Erie County Laboratory, Buffalo, New York
Fresno Department of Public Health, California
Houston Health Department, Texas
Lawrence Experiment Station, Massachusetts
Long Beach Water Department, California
Los Angeles Air Pollution Control District, California
Los Angeles County Air Pollution Control District, California
Los Angeles County Flood Control District, California
Los Angeles Department of Public Works, California
Louisville Water Company, Kentucky
Metropolitan Utilities District, Omaha, Nebraska
Metropolitan Water District of Southern California, La Verne, California
Minneapolis Water Department, Minnesota
Monroe County Department of Health, Rochester, New York
Nassau County Department of Health, Hempstead, New York
Nassau County Department of Health, Mineola, New York

Newburgh Water Department, New York
North Jersey District Water Supply Commission, Wanaque
Orange County Air Pollution Control District, Anaheim, California
Pasadena Department of Public Health, California
Philadelphia Department of Public Health, Environmental Health Laboratory, Pennsylvania
Philadelphia Department of Public Health, Public Health Laboratory, Pennsylvania
Philadelphia Suburban Water Company, Bryn Mawr, Pennsylvania
Philadelphia Water Department, Pennsylvania
Philadelphia Water Department, Belmont Laboratory, Pennsylvania
Philadelphia Water Department, Torresdale Laboratory, Pennsylvania
St. Louis County Water Company, Missouri
Springwells Filtration Plant, Dearborn, Michigan
Topeka Water Department, Kansas
Water Pollution Control Board, Cincinnati, Ohio

FEDERAL AGENCIES

Associated Universities Incorporated, Brookhaven National Laboratory, Upton, Long Island, New York
DHEW, Food and Drug Administration, Chicago, Illinois
DHEW, Food and Drug Administration, Division of Pharmacology, Washington, D.C.
DHEW, PHS, Air Pollution Technical Information Center, Division of Air Pollution, Washington, D.C.
DHEW, PHS, Communicable Disease Center, Savannah, Georgia
DHEW, PHS, Division of Dental Public Health, Bethesda, Maryland
DHEW, PHS, Division of Environmental Engineering and Food Protection, Washington, D.C.
DHEW, PHS, Information and Education Office, Division of Air Pollution, Washington, D.C.
DHEW, PHS, Interstate Carrier Branch, Division of Environmental Engineering and Food Protection, Washington, D.C.
DHEW, PHS, Northeast Shellfish Sanitation Research Center, Narragansett, Rhode Island
DHEW, PHS, Northeastern Radiological Health Laboratory, Winchester, Massachusetts
DHEW, PHS, Radiological Health Laboratory, Rockville, Maryland
DHEW, PHS, Regional Office IV, Atlanta, Georgia
DHEW, PHS, Southeastern Radiological Health Laboratory, Montgomery, Alabama
DHEW, PHS, Southwestern Radiological Health Laboratory, Las Vegas, Nevada
District of Columbia Department of Public Health, Washington, D.C.
Fourth U.S. Army Medical Laboratory, Fort Sam Houston, Texas
Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee
Pearl Harbor Naval Shipyard, Honolulu, Hawaii

Regional Environmental Health Laboratory, McClellan AFB, California
San Francisco Bay Naval Shipyard, Vallejo, California
Sixth U.S. Army Medical Laboratory, Fort Baker, California
Tennessee Valley Authority, Chattanooga, Tennessee
Tennessee Valley Authority, Wilson Dam, Alabama
2794th USAF Dispensary, Kelly AFB, Texas
USAF Hospital (HWEBB), Wright Patterson AFB, Ohio
U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland
U.S. Bureau of Sports, Fisheries, and Wildlife, Fish-Pesticide Research Laboratory, Denver, Colorado
USDI, Bureau of Reclamation, Denver, Colorado
USDI, FWPCA, Washington, D.C.
USDI, FWPCA, Great-Lakes-Illinois River Basins Project, Chicago, Illinois
USDI, FWPCA, Ohio River Basin Project, Wheeling, West Virginia
USDI, FWPCA, Pacific Northwest Water Laboratory, Corvallis, Oregon
USDI, FWPCA, Research and Training Grants Division, Washington, D.C.
USDI, FWPCA, Technical Services Division, Washington, D.C.
USDI, FWPCA, Water Quality Section, Cincinnati, Chio
USDI, Geological Survey, Columbus, Ohio
USDI, Geological Survey, Denver, Colorado
USDI, Geological Survey, Little Rock, Arkansas
USDI, Geological Survey, Philadelphia, Pennsylvania
USDI, Geological Survey, Sacramento, California
Walter Reed Army Medical Center, Washington, D.C.
Water Pollution Control Federation, Washington, D.C.

FOREIGN AGENCIES

British Coke Research Association, Chesterfield, Derbyshire, England
Central Electricity Research Laboratories, Leatherhead, Surrey, England
City's Institute for Health Protection, Belgrade, Yugoslavia
Comissao Inter-Municipal de Controle da Poluicao das Aguas E Do Ar, Sao Paulo, Brazil
Department of Health Services and Hospital Insurance, Vancouver, Canada
Department of Mines and Technical Survey, Ottawa, Ontario, Canada
Department of Municipal Laboratories, Hamilton, Ontario, Canada
Department of National Health and Welfare, Vancouver, Canada
Department of National Health and Welfare, Occupational Health Division, Ottawa, Ontario, Canada
Department of National Health and Welfare, Public Health Engineering Division, Ottawa, Ontario, Canada
Instituto Nacional de Obras Sanitarias, Caracas, Venezuela
Israel Institute of Technology, Haifa, Israel
Metropolitan Corporation of Greater Winnipeg, Manitoba, Canada
Metropolitan Water, Sewage, and Drainage Board, Sydney, Australia
Ministere de la Sante, Montreal, Quebec, Canada
National Institute of Hygienic Sciences, Tokyo, Japan

National University of Colombia, Bogota, Colombia
Newcastle and Gateshead Water Company, Newcastle Upon Tyne, England
Obras Sanitarias de la Nacion, Buenos Aires, Argentina
Ontario Water Resources Commission, Toronto, Ontario, Canada
Osaka City Institute of Hygiene, Japan
Permutit Company, Limited, London, England
Public Health Laboratory Service, London, England
Scientific Research Council, Kingston, Jamaica, West Indies
Taiwan Institute of Environmental Sanitation, Air Pollution and Radiological Health Section, Taipei, Taiwan, China
Taiwan Institute of Environmental Sanitation, Division of Water Quality and Pollution Control, Taipei, Taiwan, China
Taiwan Institute of Environmental Sanitation, PHA, Taiwan, China
Taiwan Institute of Environmental Sanitation, Taichung Water Laboratory, Taichung, Taiwan, China
Taiwan Institute of Environmental Sanitation, Tainan Water Laboratory, Tainan, Taiwan, China
Taiwan Institute of Environmental Sanitation, Taitung Water Laboratory, Taitung, Taiwan, China
Taiwan Institute of Environmental Sanitation, Training Section, Taipei, Taiwan, China
United Kingdom Atomic Energy Authority, Didcot, Berks, England
University of Beograd, Yugoslavia
University of Leeds, England
Waste Water Research Laboratory of the Swedish Forest Industries, Stockholm, Sweden
Water Research Association, Marlow, Buckinghamshire, England

UNIVERSITIES

University of California, Richmond
University of California, Riverside
University of California, Engineering Material Laboratory, Berkeley
University of California, Industrial Hygiene Engineering, Berkeley
Clemson University, South Carolina
Columbia University, Plainsboro, New Jersey
Cornell University, Ithaca, New York
University of Dayton, Ohio
Drexel Institute of Technology, Philadelphia, Pennsylvania
Fairleigh Dickinson University, Madison, New Jersey
University of Florida, College of Engineering, Gainesville
Iowa State College, Ames
University of Kansas, Lawrence
Louisiana State University, Baton Rouge
University of Minnesota, Minneapolis
University of North Carolina, Chapel Hill
University of Pittsburgh, Pennsylvania
Purdue University, Lafayette, Indiana

Rennselaer Polytechnic Institute, Troy, New York
Rutgers – The State University, Department of Agricultural Chemistry, New Brunswick, New Jersey
Rutgers – The State University, Department of Environmental Science, New Brunswick, New Jersey
St. Mary's College, Winona, Minnesota
University of Vermont, Burlington
Washington State University, Pullman

INDUSTRIES

American Cyanamid Company, Wayne, New Jersey
Anaconda Company, Grants, New Mexico
Battelle Memorial Institute, Columbus, Ohio
Bender Hygienic Laboratory, Albany, New York
Bethlehem Steel Company, Bethlehem, Pennsylvania
Bio-Technics Laboratories, Incorporated, Los Angeles, California
Borg-Warner Corporation, Des Plaines, Illinois
Brown and Caldwell Laboratories, San Francisco, California
Calgon Corporation, Pittsburg, Pennsylvania
California Water Service Company, San Jose, California
Chrysler Corporation, Detroit, Michigan
Control for Radiation Incorporated, Sandusky, Ohio
Culligan Incorporated, Northbrook, Illinois
Dow Chemical, Midland, Michigan
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Ekroth Laboratories, Incorporated, Brooklyn, New York
FMC Corporation, Pocatello, Idaho
Fairbanks, Morse and Company Research Center, Beloit, Wisconsin
General Electric Company, Louisville, Kentucky
Good Year Atomic Corporation, Piketon, Ohio
H.C. Nutting Company, Cincinnati, Ohio
Hammond-Montel, Incorporated, Elmhurst, New York
Havens-Emerson, Oradell, New Jersey
Hazleton Nuclear Science Corporation, Palo Alto, California
Holzmacher, McLendon and Murrell, Melville, New York
Industrial Chemicals, Incorporated, South Bend, Indiana
INFILCO, General American Transporation Corporation, Tucson, Arizona
Ionics, Incorporated, Watertown, Massachusetts
Johns-Manville Research and Engineering Center, Manville, New Jersey
Kem-Tech Laboratories, Incorporated, Baton Rouge, Louisiana
Kennecott Copper Corporation, Salt Lake City, Utah
Magnus Chemical, Garwood, New Jersey
Mallinckrodt Chemical Works, St. Louis, Missouri
Maryland Cooperative Milk Producers, Incorporated, Baltimore, Maryland
McCrone Associate, Incorporated, Chicago, Illinois
Midwest Research Institute, Kansas City, Missouri
Minute Maid Company, Anaheim, California

Monsanto Company, St. Louis, Missouri
NALCO Chemical Company, Chicago, Illinois
New Mexico Institute of Mining and Technology, Socorro
Nuclear-Chicago Corporation, Des Plaines, Illinois
Pacific Gas and Electric Company, Emerville, California
Pacific Gas and Electric Company, San Francisco, California
Pan American World Airways, Patrick Air Force Base, Florida
Pomeroy, Johnston and Bailey, Pasadena, California
Radiation Applications, Incorporated, Long Island, New York
Radiation Detection Company, Mountain View, California
Ray W. Hawksley Company, Incorporated, Richmond, California
Reynolds Electrical and Engineering Company, Incorporated, Las Vegas, Nevada
Roy F. Weston, Incorporated, West Chester, Pennsylvania
Sandia Corporation, Albuquerque, New Mexico
Shell Chemical Company, Princeton, New Jersey
Southern Testing and Research Laboratories, Incorporated, Wilson, North Carolina
Tracerlab, Incorporated, Richmond, California
U.S. Industrial Chemicals Company, Tuscola, Illinois
W.R. Grace and Company, Dearborn Chemical Division, Lake Zurich, Illinois
Water Service Laboratories, Incorporated, New York, New York

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